Collaborative Student Modeling by Cognitive Maps

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Abstract

The evolution of the Computer Supported Collaborative Learning (CSCL) implies the definition and managing of a Student Model (SM) regarding the collaborative group of learners capable to represent the cognitive state achieved in the Knowledge Domain acquired from the learner experiences. This model is composed by two levels, one oriented to represent the SM of each learner, and the other to recreate the SM of the team that have been learning by an a collaborative strategy. In order to accomplish this challenge, the proposal depicts Cognitive Maps (CM) to represent the concepts and their relationships that are involved in the considerations of the learners and the whole team. With this approach is possible to deal with multiples perspectives and try to ensemble them in an integral view, developing the levels of student modeling in a collaborative fashion.

1. Introduction.

CSCL approach, started to be developed in the late 1990s taking as baseline the Computer Supported Cooperative Work (CSCW) for education systems through the networked collaborative facilities available in the institutions (LAN & WAN), which had been enhanced by the Internet in order to deploy authentic virtual collaborative environments world wide. A CSCL system tries to offer a mediation service that supports the students for communicate and work in joint activities through the network, providing assistance in their coordination and application of knowledge in a certain domain. The CSCL is characterized by situations, interactions, process and effects, whose main goal is to achieve a Collaborative Learning (CL) through the model of actions, like: problem aware-recognition, investigation-analysis, planning-designing, practice-executing, self-evaluation, and presentation-documentation, described by Okamoto [1].

Along those kind of actions, the learners may perform their tasks cooperatively with various tools and applications and exchange their views via the collaborative scenario supported by the following resources: shared and personal workspace, learning content and tools, mediated dialogue channel, analyzing tools, repository for information about CL activities, reference channel for the collaborative repository and modeling tools for monitoring process of CL.

However the CSCL requires additional effort and care for identifying and deployment the suitable mechanisms to plan learning work, delivery content, coordinate learning experiences, student modeling of each learner and of the whole group, solution to conflicts, assessment, monitoring, coordination, evaluation and control among other specialize tasks [2]. Among the challenges to provide suitable learning experiences for each individual and for the whole group is the manage of the appropriate SM. Therefore, it is necessary to extend the traditional reach of the SM achieved in the Intelligent Tutoring Systems - which are usually oriented to support only one user at time – in order to meet each member profile and the one of the whole team for generating a new version called Collaborative Student Model (CSM), which is composed by the each individual SM and the Group Student Model (GSM).

Several approaches have been applied for the CSM with relative good success (see section three), but there are still several lacks in areas like the representation and integration of multiples causal views of the same student and the conformation of the GSM since the contribution of the personal SM of the members. These couples of issues are the focus of the proposal oriented to introduce an approach for the collaborative student modeling through the use of CM, which are proposed as a suitable framework for learning, knowledge representation and causal reasoning. This approach is complemented by the personal constructivism and dissonance psychological theories for depicted multiples views and deal with imbalance situations, proposed by Kelly [3]and Festigner respectively [4].
The organization of the paper is as follows. In the second section appear theoretical foundations of the CSCL as concepts and theories. In the third section some related works are described in order to illustrate some solutions. In the forth section the baseline of the proposal are introduced, including some formal models. In the Fifth section the proposal is outlined and illustrated by a case of use. The last section offers the conclusions, some discussion and the further works.

The relevance of the approach proposed in this work is to consider the cause-effect knowledge and reasoning based in cognitive maps for the student modeling.

2. Cognitive Theories

Collaboration is a coordinated synchronous activity that is the result of a continued attempt to construct and maintain a shared conception of a problem. In the education field the collaboration among the peers in a class is one of the most usual pedagogic practices and ways of socialization of the students that influences their behaviors and achievements.

The CL is the opportunity to learn through the expression and exploitation of diverse ideas and experiences in cooperative fashion. The CSCL is a kind of CL assisted by network computers as the Internet and takes as cognitive baseline the social cognitive development and the activity theories.

The social cognitive development theory proposed by Vigotsky [5] aims in the social and cultural influences on children’s cognition based in the term Zone of Proximal Development (ZPD) to describe the way human being social interactions through the learning and teaching processes with more experienced member of their culture influence. The term ZPD defines the distance between the actual development level as determined by independent problem solving and potential development as determined by problem solving under the adult guidance or in collaboration with more able peers.

Beside of the activity theory the aim is for create tangible models through the exteriorization as an important step in the learning process for making individual knowledge accessible to others through a social event that can support mutual understanding. Also the internalization for the development of thoughts and cognitive activity requires social interaction and exchange with a physical environment, which turns into mental activity.

Together the theories of Social and Activity represent interplay between individual and collective learning in a social environment by the interaction of teaching and learning roles among the peers of a group who is working collaborative fashion.

3. Related Work

In [6] are presented some classical approaches for the student modeling as the: overlay model proposed by Carr and Goldstein, where the student’s knowledge is treated as a subset of the system knowledge base; the SM is built by comparing the expert’s and student’s responses; the differences between the two are attributed to student deficiencies; the perturbation model designed by Brown and Burton provides a similar student and expert model, in which differences between the student’s and the system’s behavior are represented as perturbations, which are considered common mistakes and misunderstandings the student might make and have.

For promote awareness and foster the learning through reflection in the student, the open SM sketch the beliefs that the systems has about the knowledge acquired for the individual, in order to inform to the student for compare this view against their own beliefs about their situation. Some methods for externalizing the SM are text, tables, concept maps and hierarchical structures [7].

The active SM involves to the learner in the development and maintenance of their own model increasing the data obtained, hence the accuracy and acceptation of the SM. With this participative version is possible to cover wider cognitive aspects and take decisions for improving the performance of the student. As an example of this approach the tool VCM [8] where the learner construct concept maps that sketches their understanding of the material.

The cooperative SM is oriented to represent and combine the tutor’s and learner’s point of view to achieve a more complete SM. As an example the COSMO cooperative SM developed by Roselli [6] is based on a calculation of the student’s self-assessment. The tutor and user’s assessments are variably weighted according to the system’s estimate of the user’s self-assessment ability.

The group SM is open and active not only to the student and teacher, also is available for the scrutiny of peers, tutors and assessors involved with the learning process of the individual. With this approach is developed a rich SM recreated for several point of views to produce a more complete and useful profile of the learner. For example the I-Help [9] is based in taxonomies of purpose clichés and standard user roles to carry out typical open active learner process as student, peer, teacher or expert.

The GRACLE [10] has a SM as a set of beliefs that a mediator agent holds about its learner. The SM focuses in the commitments to perform some tasks with the group, the intentions and the group-based knowledge frontier (GKBF). This GKBF represents the opportunities of progress and assistance the learner has while being assisted by other learners in the group.
The mediator agent supports the collaboration and learning possibilities of the learners by promoting the creation of zones of proximal development as the distance between the actual development level and the potential development level of the learner. The actual development level is represented by the knowledge elements that the mediator believes have been internalized by the student; this is the set of knowledge that have been applied by the individual without the assistance from others. Meanwhile, the potential development level corresponds to the knowledge that the individual has acquired with the assistance of others. Therefore, the candidate knowledge for relevant collaboration (CKRC) consists of the intersection of these two sets.

4. Conceptual Baseline

The formal baseline of the proposal has three main supports, one regarding to the psychological field oriented to explain three issues: the cognitive process developed in the human brain by CM, how to represent diverse point of view of the same object and the dissonance that occurs often in situations where an individual must choose between two incompatible beliefs or actions. The second basis is related to the mathematic models designed for representing cognitive and causal relations and, the third basis corresponds to the modeling of the knowledge domain acquired for the student along the learning experiences.

4.1 Psychological Base

The conceptual kernel of the proposal is based in the cognitive maps proposed by Tolman [11] as the mental model produced by the people when they move around new environments. They subconsciously build a mental image of the space they are in. This mental model is encoded in the hippocampus and helps people find their way in environments that they have visited before and remember the structure of the place. Visualizations are a way of cognitive method that allows the individual to represent knowledge, memorizing, recall and make inferences about the layout information characterized as CM. The CM is essentially a network of representations coding both the places and the sequential and causal relations between them.

The second basis is the personal construct theory developed by Kelly [3], which provides an approach for representing an individual’s multiple perspectives according to the guideline that suggests in order to understand how the individuals organize their environments requires that subjects themselves define the relevant dimensions of that environment.

The third basis is the cognitive dissonance theory formulated by Festinger [4] for explains the distressing mental state that people feel when they find themselves doing things that don’t fit with what they know. Two factors affect the strength of the dissonance: the number of dissonant beliefs and the importance attached to each belief. According to the theory, the individuals tend to seek consistency among their cognitions (i.e., beliefs, opinions), when there is an inconsistency between attitudes or behaviors, something must change to eliminate the dissonance as reducing the importance of the dissonant beliefs, adding more consonant beliefs that outweigh the dissonant beliefs or changing the dissonant beliefs so that they are no longer inconsistent.

4.2 Formal Models of the Cognitive Maps

Since the findings of Tolman, Axelrod [12] developed a computational version of the CM based in the causality for modeling spatial learning, knowledge representation and causal reasoning supported by cause-effect relations that occurs among concepts of the environment modeled. Axelrod described a CM as (1):

\[(1) \cdots CM = (C, A)\]

Where CM is a digraph composed by the concepts of the domain represented as nodes (C), and the relationships among the concepts represented as arcs (A) that link the nodes. In the digraph, there are basically positives (+), negatives (-) or neuters (0) causal relations in (C).

When a cause concept stimulate in direct way to an effect concept a positive arc is used. This means whether there is an increase of value in the origin concept also there will be stimuli to improve the state of the effect concept, but if the cause concept is decreased also there will be a similar consequence on the effect concept. The negative arcs represent effects that stimulate in inverse way the cause concept with the effect concept. The neuter relation means none arc between two nodes or besides of the existence of an arc no effect is produced by the cause concept against the effect concept.

Two concepts i and j, can be linked by a direct causal relation (DCR) through only one arc between the concepts i and j, or by an indirect causal relation (ICR) where there is a path that links i with j through a chain of arcs that cross by one o more intermediate concepts, which propagate the effect by the syllogism hypothetic principle. In general, between two concepts i and j, could there be none or one DCR and none, one or several ICR. The final total causal effect between two concepts i and j is estimated by the sum of the direct plus the indirect causal relations that link them.
The use of causal values is determined by the laws of the sum (\( + \)) and multiplication (\( * \)) in the way that is briefly show in (2) and (3) respectively for any \( x, c \in C \):

\[
(2a) \ 0 \ y = y; (2b) \ y \ y = y; (2c) \ x \ y = yxr \quad ; \quad (2d) \ x \ y = y \ x
\]

\[
(3a) \ 0 \ y = 0; (3b) \ y \ y = y; (3c) \ - \ - = \ + ; (3d) \ x \ y = y \ x
\]

In the case of (2c) the symbol \( \in \) means the occurrence of any causal value \( (+, -, 0) \). For represent a CM it is used a square matrix \( A \) with \( n \times n \) elements corresponding to the number of concepts. An entry \( A_{ij} \) shows the value of the arc that links the cause concept \( i \) with the effect concept \( j \).

On the matrix model several basic operations are applied: The sum operation gets the effect of a DCR by the equation (4). The multiplication operation estimates the total effect produced by an ICR through the equation (5). The \( n \times n \) matrix power obtains the total effect of one concept on another by the number of elements that integrate the longest path between them \( (i \ and \ j) \) by the equation (6). With these operations is possible to compute the total causal effect \( A_{ij} \), which is the total effect matrix that has as its entry \( ij \) the total effect of \( i \) on \( j \) through the equation (7). Finally, the equation (8) means that the sum is monotonic, because implies that there is a \( k \), such that represents the number of arcs that compounds the longest path, between the \( i \) and \( j \) concepts.

\[
(4) \quad (A \mid B)_v = A_v \mid B
\]

\[
(5) \quad (A \times B)_v = (A_v \times B_j) \cdots (A_n \times B_n)
\]

\[
(6) \quad A' := A; \quad A^2 := A \times A
\]

\[
(7) \quad A' := A' \times A\times \cdots
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\[
(8) \quad A' := A' \times A' \times A^2 \times \cdots \times A
\]

### 4.3 Formal Model of the Student Model

In relation to the **student modeling** the traditional approaches consider the SM of a specific learner, trying to characterize three types of knowledge profiles: domain-independent, cognitive skill and domain-independent. The universal concepts, underlying assumptions and common sense, vocabulary and social fundaments for interacting are represented by the domain-independent SM (I).

The learning preferences, skills and behavior of the student that offer special insights about the personality and performance of the learner are managed by the cognitive SM (C). Finally, the domain-dependent SM (D) posses the knowledge that the system believes that the student has acquired about the domain of the education provided, which is organized in three categories tasks, logical and physical elements to describe the user goals, the beliefs of the system regarding to the student and the records of the user’s inferred knowledge respectively.

A useful definition for any type of SM is described by Self [13] and Koch [14] based in the beliefs and knowledge that the system and the actors-student have. Beliefs (\( B \)) are represented by formulas from the propositional calculus, where the objects of belief are propositions \( p \) that may be true or false according to the perspective of the system (\( s \)) or the actor-student (\( u \)). Then a set of propositions that the system believes is show in (9). As \( Bsp \) are propositions that means that beliefs can be nested, then the set of propositions \( p \) the systems (\( s \)) believes \( (Bs) \) are believed by a student \( (Bu) \) is defined as \( (Bu) \) in (10). But as the system unknowns the user’s beliefs, all reasoning has to be done on the system’s beliefs. Therefore the subset of beliefs that the system has about the user is the student model (USM) defined in (11).

\[
(9) \quad Bs = \{ p \mid Bsp \}
\]

\[
(10) \quad Bu = \{ p \mid Bs Bup \}
\]

\[
(11) \quad USM = Bu (U) = \{ p \mid Bsp (U) \}
\]

The beliefs (\( B \)) could be replaced with knowledge (\( K \)): a system (\( s \)) knows \( p \) if \( Ksp = Bs, p \) is true and there is a source for knowing \( p \) is true. At least with this basis, it is possible to define any type of SM, as for example the domain-dependent SM (D) is declared in (12) as the set of propositions related to the domain \( (D) \) that the system \( (s) \) believes and next is enhanced in (13) as the set of propositions related to the domain \( (D) \) that the system \( (S) \) believes the user \( (U) \) has. The other two models are obtained based in (13) and replacing \( (D) \) by \( (I) \) and \( (C) \) for generating (14) and (15). Then finally these models leads to the complete SM defined in (16) (USM):

\[
(12) \quad Ds = \{ p \mid Bsp \} \cap \{ p \mid p \in D \}
\]

\[
(13) \quad Ds (U) = \{ p \mid Bsp (U) \} \cap \{ p \mid p \in D \}
\]

\[
(14) \quad Is (U) = \{ p \mid Bsp (U) \} \cap \{ p \mid p \in I \}
\]

\[
(15) \quad Cs (U) = \{ p \mid Bsp (U) \} \cap \{ p \mid p \in C \}
\]

\[
(16) \quad USM = Ds (U) \cup Is (U) \cup Cs (U)
\]

### 5. Case of Use of the Approach

The approach for Collaborative Student Modeling aims for integrate several properties of the individual and group SM, the cognitive theories and the conceptual baseline described earlier, in order to recreate a rich, plural and unique point of view from several perspectives based in the user-role (as system, teacher, expert, coach, student, peer and assessor) at individual and group level, considering the some achievements of open, active, cooperative and group SM, through the framework that is described and illustrated along this section.
5.1 Strategy

The approach follows a bottom-up strategy along several layers of development. The starting point at the bottom layer \{1\} corresponds to SM done for each individual of the group since the point of view of each user that means i.e. if 5 students integrate the group and there are 4 actors modeling each SM (the system, the student, one peer and the teacher) then there will be 20 versions of SM in total (4 by each individual). But if we consider that the SM is organized in 3 types of SM (cognitive, dependent and independent domains) then the total will be (5 students * 4 actors) * 3 (types) = 60 SM.

The next upper level \{2\} represents the integration of the multiples views defined for the actors for each type of SM in order to produce the unique version of the three types of SM for each individual. Following the example, it has (5 unique SM) * 3 (types) = 15 SM.

The following upper level \{3\} corresponds to the basic version of each type of SM for the GSM, that means 3 types of GSM that are organized in two models each one as follows: the intersection (\(\cap\)) and the union (U) of the SM of each student recreates a common and potential image of the whole group respectively. Where the common profile is depicted by the properties that all the members have and manage in an acceptable level; and the potential profile is the result of the attributes that each member poses and use in an acceptable degree.

Therefore the common profile is equivalent to the actual development level and the potential profile is similar to the potential development level from the Vigotsky’s theory. In consequence the candidate knowledge for relevant collaboration consists of the intersection of these two profiles producing the third candidate profile. Following with the example, (3 types GSM dependent, independent and cognitive) * (3 profiles: common, potential and candidate) = 9 GSM. This is supported by three instances (common, potential and candidate profiles) of the equations 13, 14 and 15 (for dependent, independent and cognitive models).

The top level \{4\} represents the union of the three domain models (dependent, independent and cognitive) in a complete version for the GSM, but according to the three profiles (common, potential and candidate) there will be three physically GSM, although conceptually speaking will there be only one. This version of GSM is volatile and has to be updated according to progress of the services education provided in a collaborative fashion to the students along the time. The strategy goes from the particular point of view regarding to the three domains expressed for the users interested in a specific student, fixes them in a unique SM version for each domain.

Afterwards, the process integrates the first GSM for the three domains and produces three profiles that offer specific guidelines about the homogeneous (common) condition of the group as if they were a single individual, the potential (potential) that is in the particular attributes that one member has and the other no yet, and finally the support (candidate) that could offer the member that have the knowledge, skill of background to the others that are missing in a collaborative fashion. The final stage is useful to compare the global knowledge of the group against the knowledge expert; also for identify cognitive skills and constraints of the group and the lack of independent knowledge to be reinforced.

5.2 Guidelines

Since the strategy outlined, some guides for developing the four stages (one for each layer) are detailed next. First of all, the general model for represent any level (individual and group), domain (dependent, independent and cognitive) and profile (common, potential and candidate) is based in CM that represent qualitative knowledge (through the nodes) and make causal inferences through the causal links (using the principles suggested by Tolman and Axelrod).

Second, any CM has the facilities to show and manipulate its content, beside of make some exploitations through the causal inferences that are able to predict possible outcomes and explain situations. Third the CM make easy identify the conflicts among the point of views of the user about the same student (based in the approach of Kelly). Forth the mechanism for dealing with the conflicts is supported by the contribution of the dissonance theory for qualitative decisions making by a mediated mechanism.

With these baselines, the behavior specification is depicted in a graphical way through the causal arcs and values that links the concepts. The inference mechanism is activated since the input concepts (those that no arcs arrive to them) through the direct paths that link them with other concepts at first step. In the followings steps an indirect causal effect is estimated based in (3) along the concepts that conform the causal paths until arrive to the end of the path represented by an output concept.

If the CM is acyclic, then the effects coming form each path that links a concept node \(i\) with the output concept \(o\) are added by (2) until arrive the causal effect produced by the longest path (8). Therefore a stable state is achieved. But if the CM is cyclic, then as soon as the first causal effect (coming from the shortest path that links \(i\) with \(o\)) arrives, the feedback is initiated producing dynamic situations whose values are changing according to the nature of the causal relationships.
5.3 Development

The deployment of the strategy based in the guidelines given before is described in this section through the stages of the framework in bottom-up order, applying the concepts to a student modeling case, sketching its evolution by a series of figures and tables.

{1} In the first layer for each student of the group are created three basic CM domains related to the three stereotypes of CM specialized in dependent, independent and cognitive domains that are instantiated with the particular attributes of the learner. The knowledge elicitation could be achieved by interviews, observation, exercises and tests that each user have to develop regarding to the object student. The outcome is the three personalized CM of the learner according to the particular point of view of each actor, who according with his role, focuses in specific attributes of the student.

For example, the dependent-domain CM of the student A, produced by the actor C (coach) is depicted in the Figure 1, which is related to the study of object oriented programming with Java by the exposition of seven concepts (a to f) and the arcs labeled with + and – causal relations. Therefore according to the laws of the | and * (notations 2 and 3) is possible appreciate that the input concept (a) affects negatively to the concept (c) but positively to the concept (d), and through (d) affects indirectly negatively to the (f) output concept; then the concept (f) feedbacks positively to concept (c).

As an example of the maintenance of the SM, the Figure 2 depicts the new version of the dependent CM for student A updated by the Coach, and the Figure 3, exhibits the same object but described by the proper student.

{2} The second layer integrates a unique image of each SM domain since the multiples views depicted out by the actors. For this purpose are used adjacency matrixes of clausal values of the CM, as the showed in the Tables 1 and 2. These matrixes correspond to the Figures 2 and 3 respectively. Thus the models are joined in an integral matrix, as the depicted out in the Table 3 where there are entries with none, one or more values. The first value in any entry corresponds to the coach’s view and the second value to the student’s view. Entries with only one value mean a unilateral view, entries with two equal values represent a common view, but if the values are different identifies a conflict. E.g. in Table 1, the entry ac has the value +, corresponding to the arc that comes from concept a to c; whereas in Table 2, the value is – for the same entry. Wherefore in Table 3, the values are +, - in ac.
Table 1. Dependent domain knowledge matrix of the Student A, updated by the coach

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Table 2. Dependent domain knowledge matrix of the Student A, updated by the student

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Table 3. Unique dependent domain knowledge matrix of the student A

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The Table 3 would manage so number of values as the number of user’s multiple views exist. In the example for simplicity appear only two values. After the creation of the matrix, the unilateral views and the conflicts have to be resolved by the use of specialized services of negotiation and mediation carried out by agents as is proposed by Chaib-draa [15]. But in this approach, these two functions are enhanced by the theory of dissonance due to one or several user’s point of views has to be changed. Therefore a special mechanism based in these three approaches is conceptualized for qualitative decision making according to the following specifications:

The negotiation is the process where the agent responsible of each view offers arguments in favor of the existence or not of the concept, causal relation or causal value for a specific relation that represents. This agent tries to add more consonant beliefs in order to convince its peers to do the appropriate changes for achieve an agreement.

The mediation is carried out by a neutral agent for interact with the agents responsible of each view in order to arrive a mutually satisfying arrangement through the reduction of the importance of the dissonant beliefs and the change of the dissonant beliefs, so that they are no longer inconsistent. The final result is a new integrates student’s CM for his three domains, like the showed in the Figure 4, for the case that is developing.

Figure 4. Student A’s unique dependent domain knowledge CM

{3} The third layer takes the three unique domain CM of each student of the group and creates a unique CM for each domain of the group with the three profiles. Therefore three integral matrices are created for each domain. The first one corresponds to the common profile (∩) recreated by the properties that all the members have. The second matrix represents the potential profile (U) with all the attributes that the students have. And the third matrix is the candidate profile as the result of the common (∩) potential profiles.

{4} The forth layer applies the union of the three domains based in (16) for generate a unique GSM divided in the common, potential and candidate profiles. For the current state, this GSM is useful for adapt the learning experiences to the student and to the whole group for the next step. As a result of the new sessions other cycle for update and maintenance the student model is done in the way yet explained.
Conclusions

The collaborative student modeling implies a great and constant effort that runs along the whole education process beside of other services. The proposal described tries to integrate the different versions of the single SM, calling for the active participation of the student in the design and maintenance of his own SM in a collaborative fashion with other actors.

Also, the proposal integrates the several SM of each member of the group and establishes the common knowledge, which represents the potential that the entire group offers and encourages to the help among peers in order to generalize the knowledge, skills and background of all the members like one individual student.

This approach is based in Cognitive Maps due to it is easy to model cognitive process, it is affordable for represent knowledge and it has a simple but useful inference mechanism for predictive causal outcomes (that will be explained further).

Currently, this work is at design phase, dealing with the specification of the mechanism for negotiation and mediation based in dissonance theory. Also it is considered enhanced it through the qualitative decision theory in order to deploy an automatic integration of the multiples views that produce the unique Student Model.

References


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